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Atmospheric Neutrino Flux Calculation with FLUKA: update and first results on prompt contribution

G. Battistoni[a], A. Bruno[b], F. Cafagna[b], P. Desiati [e], J.C. Diaz-Velez[e], A. Ferrari[a,c], T. Montaruli[b,d], P. R. Sala[a], A. Tamburro[e]

(a) I.N.F.N., Sezione di Milano, Via Celoria 16, 20133 Milano, Italy
(b) Dipartimento di Fisica and I.N.F.N., Sezione di Bari, Via Amendola 173, 70126 Bari, Italy
(c) presently on leave at CERN, CH-1211 Geneva, Switzerland
(d) presently on leave at University of Wisconsin-Madison
(e) University of Wisconsin-Madison, 1150 University Ave, Madison, WI 53706, US
Presenter: F. Cafagna (francesco.cafagna@ba.infn.it), ita-cafagna-F-abs2-he13-poster

We show the results of the update of the atmospheric neutrino calculation based on FLUKA considering the interaction of primary nucleons up to 10^6 GeV/nucleon. A new primary spectrum is proposed to solve a deficit in high energy (∼100 GeV) neutrinos in the calculation of 2001, and our results are compared against other recent calculations. In addition we show for the first time our results on prompt neutrinos and muons coming from the decay of short-lived heavy quark states. They are a serious and still highly uncertain source of background for neutrino telescopes, since their spectrum is harder than that of neutrinos from pion and kaon decays.

1. Introduction

In this work we present an update of the FLUKA[1] atmospheric neutrino flux calculation. Respect to the simulation set-up used in the previous FLUKA calculation [2], a new all particle spectrum has been used, while focus has been placed in tagging secondaries resulting from the decay of short-lived charmed mesons.

The semileptonic decay of heavy quark charged particles gives rise to a prompt component of the total atmospheric neutrino flux. This component becomes more and more significant for neutrino energies above ∼1 TeV while the conventional component, mainly due to the pion and kaon decay chains, decreases. This feature makes the neutrino flux prompt component an irreducible background for large volume neutrino telescopes like ANTARES, AMANDA, IceCube or NEMO [4]. Among other motivations for the study of the prompt neutrino component we cite, for example, the possibility to probe the charm production cross section at high energy or for probing cosmic rays in a very small x region, not reachable at colliders [3]. For this reason it is important to fully characterize this component respect to the overall components of the cosmic ray showers in the atmosphere.

The FLUKA precise simulation offers an ideal framework, not only capable to tag and isolate the prompt component but also to study it respect to all the other conventional components. For the first time the neutrino prompt component has been studied in the framework of a complete and precise simulation of atmospheric showers.

2. The simulation set-up

Respect to the previous FLUKA atmospheric neutrino flux calculation [2] a new all nucleon primary spectrum has been adopted. The new spectrum has been calculated using the so called ICRC2001 one[9] up to 100 GeV. For the proton component at energies larger than 100 GeV, using the normalization obtained at 100 GeV, we assumed a spectral index of $\gamma = -2.71$ to improve the agreement between the predicted fluxes and the MACRO and Super-Kamiokande throughgoing muon data[13]. Above the *knee* at 3000 TeV, we assumed a spectral index of $\gamma = -3.11$.

For what concerns the He component, above 100 GeV we used a $\gamma = -2.59$ and a charge dependent *knee*

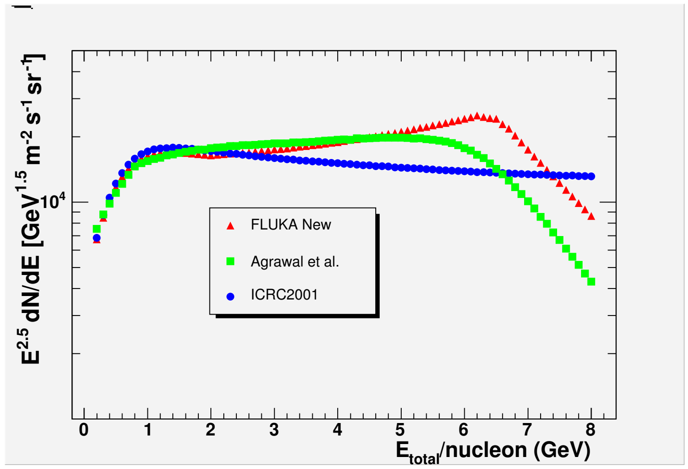

Figure 1. The new all nucleon primary spectrum adopted for this work compared to the ICRC2001 [9] and the Bartol 1996[8] ones. Spectra are reported multiplied by $E^{2.5}$.

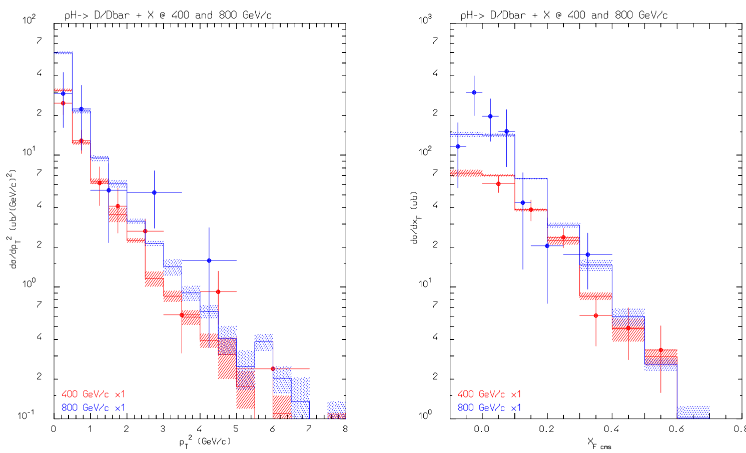

Figure 2. Comparison of FLUKA differential cross section (histogram) with pp collision data (points) [11] at 400 and 800 GeV/c into $D/\bar{D}$ versus Feynman x and transverse momentum.

has been assumed according to the rule: E_{knee}/nucleon= $Z \times 3000\ TeV/A$. Higher Z components have been grouped in CNO, MgSi and Fe sets and treated using an all-particle spectrum with the above cited charge dependent *knee* parametrization. The resulting all-particle spectrum is reported in figure 1 and compared to the ICRC2001 and previous Bartol 1996[8] fits.

For the first time the possibility of tagging FLUKA secondaries produced in charmed meson decays has been exploited making it possible to separate the contribution of the prompt component of neutrinos and muons from the conventional one up to the higher energies.

FLUKA is a transport and interaction code widely benchmarked against collider data and theory. For example a comparison of the FLUKA differential cross section with pp collision data at 400 and 800 GeV/c[11] into $D/\bar{D}$ versus Feynman x and transverse momentum is shown in figure 2. Thanks to this crosschecks a big improvement in the detail of the charmed production of prompt particles has been obtained[10].

The simulation set-up ot the FLUKA atmospheric neutrino simulation, has been described in [2] and benchmarked on the Caprice 94 atmospheric data[12]. Primaries have been generated at an altitude of ∼100 km and tracked in an isothermal atmosphere reduced in a set of 100 shells of different altitude and air characteristics while relevant parameters for secondary muons and all neutrino flavors have been scored at sea level.

3. Results and discussion

At the time of writing a total of $\sim 87 \times 10^6$ primaries has been generated in the range $0.5 \div 10^6$ GeV/nucleon. Statistics are still under collection, especially at high energies, and updated results will be presented at the conference. In figure 3 we present the total flux of muon neutrinos. The spectrum is compared to the differential energy distributions from Bartol[5], HKKM[7] and Lipari[6] works. The ratio shown in figure 3 should be considered as preliminary at high energies. In that region discrepancies between calculations could be due to a different treatment of the *knee* in the primary spectra.

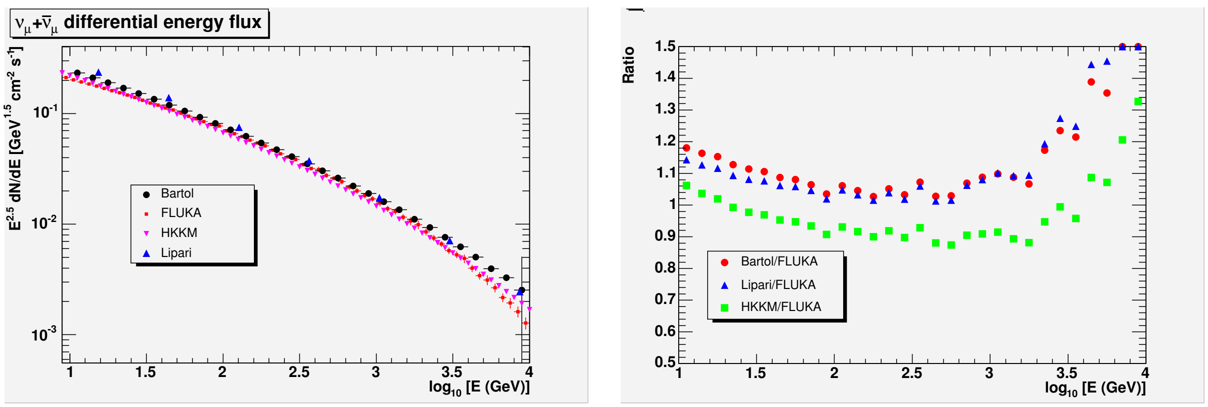

Figure 3. The total muon neutrino spectrum, scaled by $E^{2.5}$, compared to the Bartol[5], Honda[7] and Lipari[6] ones

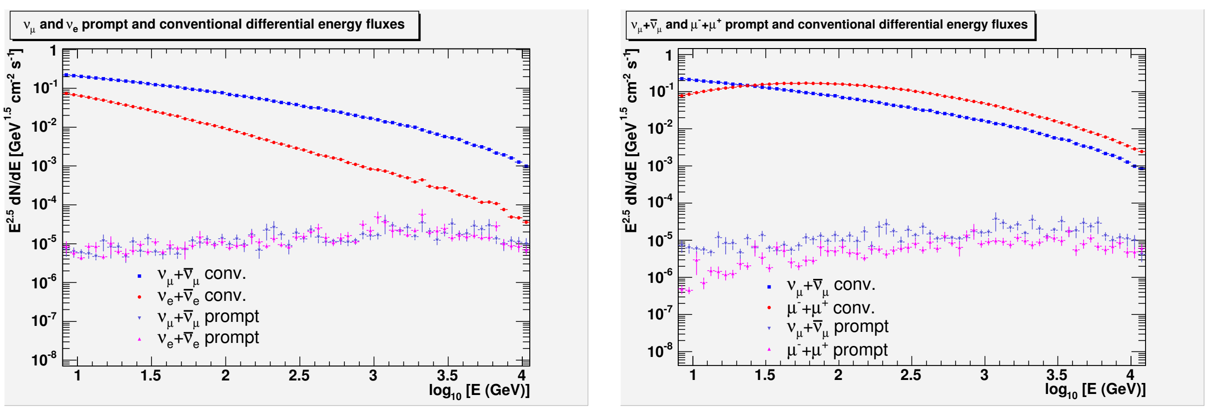

Figure 4. Comparison of the prompt neutrino spectra to the conventional ones for: ν_μ and ν_e, on the left, and ν_μ and μ, on the right. All fluxes are integrated over the full solid angle and multiplied by $E^{2.5}$.

The peculiar feature of this work is highlighted in figure 4 where conventional spectra of both muon and electron neutrinos are compared to the prompt ones. A slightly increase of the prompt fluxes while approaching the crossover energy is evident.

Besides the prompt neutrinos, we tagged also the prompt muons. As for prompt neutrinos, prompt muons are tagged when created in the tracking procedure and isolated in the scoring collection routines. The corresponding spectra are reported in figure 4. The muon fluxes were collected from the whole solid angle. This is a comparison with the neutrino fluxes from the kinematical point of view. As a matter of fact it is noticeable the effect of muon decay below $\sim$30 GeV and of the enhancement of the muon flux at higher energies due to the larger energy fraction taken by the muon in the meson decays. The similarity of the prompt muon and neutrino fluxes is another feature: the neutrino one is larger (through the statistics still prevents to quote a number) in agreement with [14].

In the future we plan to calculate the fluxes for neutrino energies larger than 10^4 GeV, using the DPMJET-III model incorporated in the FLUKA transport code.

4. Conclusions

For the first time we report on the spectra of the prompt neutrino and muon components, though with still preliminary statistics, of the atmospheric neutrino fluxes. These spectra has been calculated and studied using FLUKA tagging the secondary produced in the decay chain of charmed mesons. For this calculation an update of the FLUKA simulation set-up has been used along with a new all-particle primary spectrum.

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